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Petrogenesis and mantle source characteristics of Quaternary alkaline mafic lavas in the western Carpathian–Pannonian Region, Styria, Austria

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ABSTRACT

In the Styrian Basin, i.e. the westernmost part of the Carpathian–Pannonian Region (CPR), the Pliocene to Quaternary post-extensional phase was accompanied by eruption of alkaline mafic magmas, some of which carry mantle xenoliths. The rocks range from nephelinites (Stradnerkogel and Waltrafelsen) to (predominant) basanites and *ne*-basanites (Klöch and Steinberg). They have high Ce/Pb, Nb/U and Nb/La ratios reflecting asthenospheric mantle source characteristics with negligible crustal contamination, differentiation *en route* to the surface and/or interaction with the lithospheric mantle. The calculated depths of magma generation are $>$100 km for the basanites and *ne*-basanites in comparison to 135 km or more for the nephelinites, implying an origin in the garnet stability field. The temperatures of mantle melting for the basanites and *ne*-basanites are from ≈1400 to 1500 °C.

Modeling calculation using the most primitive Styrian sample (a basanite) gives a mantle potential temperature (Tp) of 1466 °C similar to average Tp of upper mantle sources beneath MORB indicating that the Styrian magmas were generated from asthenospheric mantle sources at ambient temperatures that preclude plume activity beneath the study area.

The nephelinites have elevated Zr/Hf (51–67) and La/Yb_N (29–31) ratios and negative K and Ti anomalies on the PM-normalized multi-element diagrams, similar to those of carbonatites. These characteristics suggest that their source had experienced enrichment by carbonatitic liquids; an inference supported by their estimated content of ~5% CO_2. By contrast, the trace element signatures of the basanites and *ne*-basanites suggest that their asthenospheric source, which experienced higher degrees of melting than the nephelinites, was nearly unaffected by carbonatite metasomatism. From the overall similarity of the trace element distribution patterns and the narrow range of their Sr–Nd isotopic ratios, all the rocks can be related to a similar (OIB-like) asthenospheric mantle source, approximating the European Asthenospheric Reservoir (EAR-type).

1. Introduction

The Neogene to Quaternary evolution of the Carpathian–Pannonian Region (CPR; Fig. 1) was accompanied by extensive volcanism that produced a wide spectrum of magmatic rocks (Embey-Isztin et al., 1993; Balogh et al., 1994; Embey-Isztin and Dobosi, 1995; Harangi et al., 1995, 2006; Pécskay et al., 1995, 2006; Harangi, 2001; Seghedi et al., 2004a,b; Ali and Ntaflos, 2011; Seghedi and Downes, 2011). Three main types of magmatism were recognized: i) large-volume silicic ignimbrites and tuffs with calc-alkaline affinity, in the Early to Middle Miocene, ii) intermediate (mainly andesitic) calc-alkaline subduction-related volcanic rocks in the Mid-Miocene to Recent and iii) alkaline basalts of Late Miocene to Recent age that occur sporadically throughout the CPR. The calc-alkaline and alkaline magmatism reflect their source compositions (lithospheric and asthenospheric, respectively) (Seghedi and Downes, 2011). The alkaline volcanism represents small volume magmas erupted through transtensional faults and indicates a change from lithospheric to asthenospheric melting (Seghedi and Downes, 2011). In the CPR, alkaline mafic volcanism (Fig. 1) ranges in age from Late Miocene (~11 Ma, in Burgenland) to Quaternary (e.g. Nógrád, Styrian Basin, eastern Transylvania and SE Carpathians) (Embey-Isztin et al., 1993; Balogh et al., 1994; Downes et al., 1995; Seghedi et al., 2004a, 2010; Pécskay et al., 2006).

Setting aside a few exceptions, the alkaline mafic volcanism (Fig. 1) is distributed in a diffuse way around the periphery of the CPR, a typical back-arc setting. A major issue, which was repeatedly addressed in the past but which remains the subject of intensive debate, is the origin of this magmatism. Embey-Isztin et al. (1993) concluded that the alkaline lavas in the CPR are of asthenospheric origin. In the central part of the CPR, these lavas reacted with melts from the lithospheric mantle that had previously been affected by subduction related components. Evidences for this reaction, according to Embey-Isztin et al. (1993), are the similarities between the alkaline lavas and

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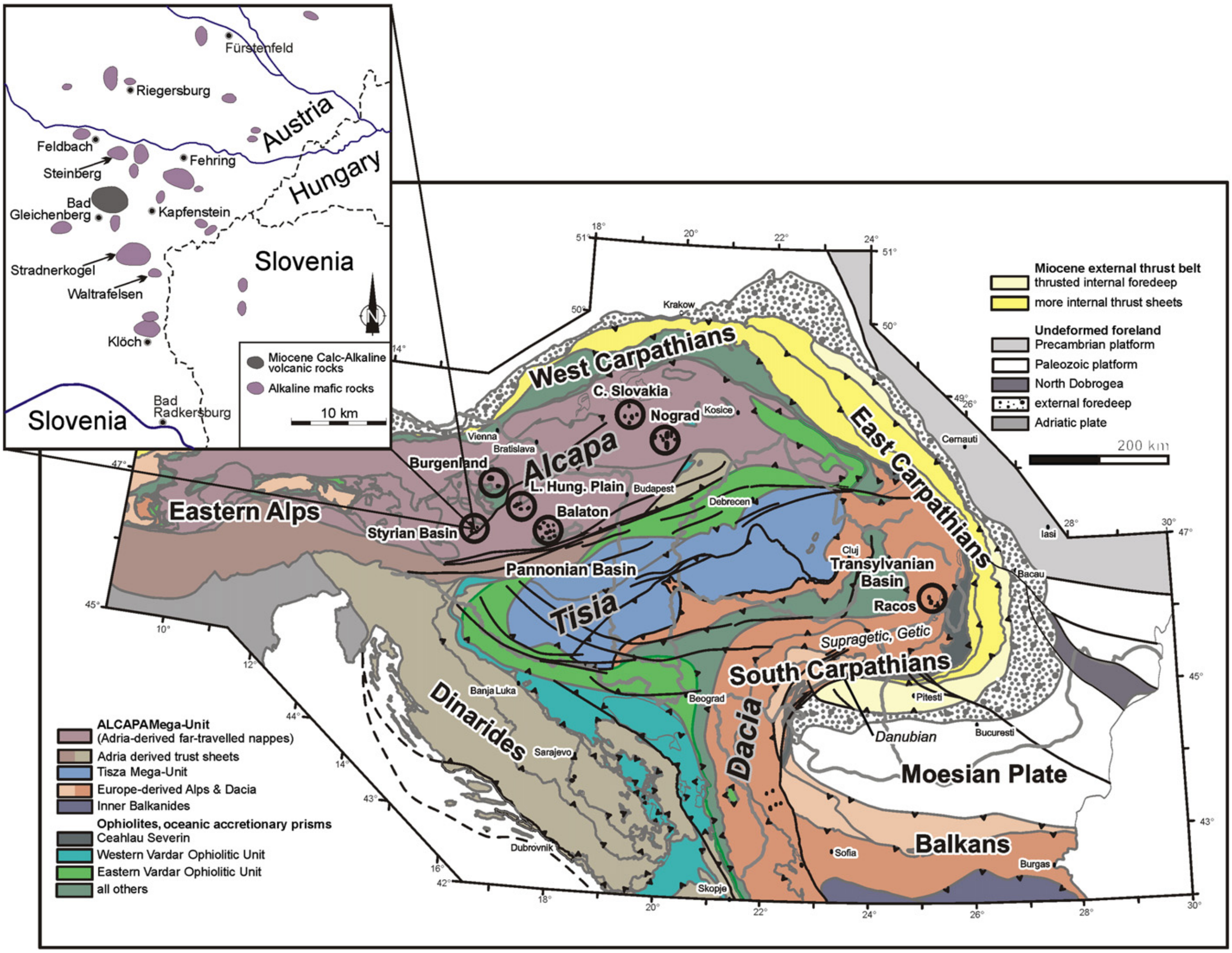

Fig. 1. Distribution of Late Miocene–Pleistocene alkaline basalts within the Carpathian–Pannonian Region (modified after Schmid et al., 2008) and location of the Styrian Basin volcanic centres.

Dupal OIB (Ocean Island Basalts) and their enrichment in large ion lithophile (LIL) elements. Geochemical signatures indicate that alkaline basalts from the northern and western margins of the CPR are also of asthenospheric origin but they did not react with lithospheric mantle (Embey-Isztin et al., 1993). Furthermore, Embey-Isztin et al. (1993) found that the alkaline lavas towards the periphery of the basin were products of lower degrees of partial melting than those in the more central areas. To explain the petrogenesis of the alkaline magmas in the area, Embey-Isztin and Dobosi (1995) invoked an upwelling asthenospheric plume, belonging to the European Asthenospheric Reservoir (EAR) that initiated lithospheric extension, triggering magma generation in the asthenosphere. However, geochemical studies by Harangi and Lenkey (2007) provided arguments against the EAR and the existence of "mantle plume fingers" or "baby plumes" (Cebriá and Wilson, 1995). According to Harangi and Lenkey (2007) the young magmatism can be attributed to low degrees of melting of a heterogeneous asthenospheric source at temperatures close to solidus, brought about by Miocene lithospheric extension. More recently, Ali and Ntaflos (2011) in a detailed study of the Burgenland alkaline basalts in the western margin of the CPR argued against a plume beneath the Pannonian Basin as the calculated mantle potential temperature (Tp = 1386 °C) is too low to support this concept. We conclude that the generation of the alkaline magmatism in this part of the CPR was the result of passive upwelling of asthenospheric mantle, with resultant small-scale melting, in conjunction with late Miocene lithospheric extension (i.e. "adiabatic decompression melting").

To help clarify the complex geodynamic settings of the CPR, this study presents new data (major and trace-elements and radiogenic isotopes) from and insights about the young alkaline basalts from the Styrian Basin, at the westernmost margin of the CPR.

2. Geodynamic setting

The Pannonian Basin (Fig. 1) in eastern Central Europe formed during the Neogene as an extensional back-arc basin (e.g. Horváth et al., 2006). It comprises two tectonic terrains, the ALCAPA (Alps-Carpathians-Pannonia) to the northwest and Tisza-Dacia to the southeast. The Pannonian Basin, including sub-basins such as the Styrian Basin, formed as a result of the northward motion of the Adriatic plate and its collision with the European continent in the late Oligocene. This collision caused gravitational collapse of the Eastern Alps and stimulated lateral extrusion (E-NE) of the tectonic terrains during late Oligocene to early Miocene times (Horváth et al., 2006). The Alcapa terrain detached from the Southern Alps and extruded eastward with a counter-clockwise rotation, whereas the Tisza–Dacia terrain moved north-eastwards with a clockwise rotation due to compressive stresses. The two terrains assembled in the early Miocene to form the Pannonian unit which then underwent extension. The latter occurred in two main stages: i) Early